

GRANT TITLE: Basic Research on the Composition of Heavy Cosmic Rays-The Trans-Iron Galactic Element Recorder Experiment (TIGER)

FINAL REPORT

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TIGER INVESTIGATORS

The Trans-Iron Galactic Element Recorder (TIGER) investigation was funded through NASA grants to these US institutions:

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Caltech: Dr. E.C. Stone PI; Dr. Richard A. Mewaldt, Dr. Stephen M. Schindler, Co-I's
Goddard Space Flight Center (NASA): Dr. Louis Barbier PI; Dr. Eric R. Christian, Dr. Georgia deNolfo, Dr. John Mitchell, Dr. Jay R. Cummings Co-I's
University of Minnesota, Dr. C.J. Waddington is an unfunded Co-I

TIGER OBJECTIVES

Among the most fundamental astrophysical problems is understanding the mechanism by which particles are accelerated to the enormous energies observed in the cosmic rays. That problem can be conveniently divided into two questions: (1) What is the source of the energy and the mechanism for converting the energy of that source into the energy of individual cosmic-ray nuclei, and (2) what is the source of the material that is accelerated and the mechanism for injecting that material into the cosmic-ray accelerator?

There is a general consensus that the answer to the first of these questions, for nuclei with energy $<10^{14}$ eV, is that the source of their energy is almost certainly from supernova explosions (e.g., Ginzburg & Syrovatskii, 1964).

The answer to the second question is still uncertain, although evidence in favor of a superbubble origin of cosmic rays is becoming quite significant (Higdon et al, 2203 and Binns, 2005 (Submitted to ApJ). There are several ways of interpreting available data that lead to quite different models for the source of the material and its injection mechanism. With the TIGER instrument we have obtained data that will help to distinguish among these possible models.

The TIGER experimental objective is to measure the abundances of the very rare nuclei with charge (Z) $30 \leq Z \leq 40$ to help distinguish between these models.

TIGER FLIGHTS

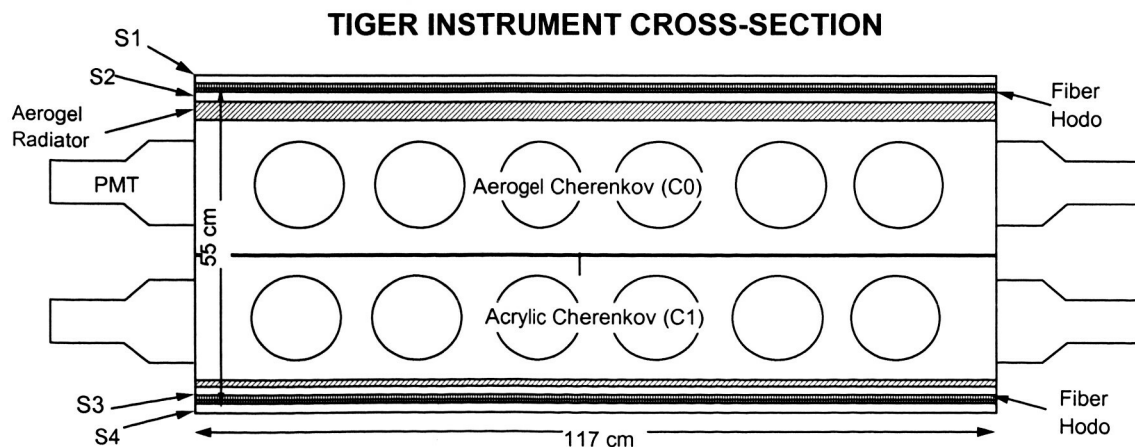
Flights from Antarctica--The Trans-Iron Galactic Element Recorder (TIGER), an instrument designed to detect and measure the abundances of cosmic ray elements with atomic number (Z) between Neon ($Z=10$) and Zirconium ($Z=40$), was first flown from McMurdo, Antarctica, aboard a long-duration balloon (LDB) from Dec. 21, 2001 to Jan. 21, 2002. TIGER flew for 31.8 days, circling the South Pole twice and setting a new record for LDB flight duration. The altitude of the flight varied between 108,000 and 128,000 feet. The TIGER experiment was refurbished and flown on a second flight from Dec. 17, 2003 to Jan. 4, 2004. On this flight, we flew for a total of 18 days at an altitude that varied from 121,000 and 134,000 feet.

During the first Antarctic flight we recorded $\sim 373,000$ of the relatively abundant cosmic-ray iron ($Z=26$) nuclei, and ~ 100 of the very rare nuclei with $Z > 30$. On the second flight we detected $\sim 241,000$ iron nuclei. Using data from the 2001 flight we have obtained clear peaks for elements with $Z=30, 31, 32, 33$, and 34 . These are the best measurements obtained to date for the nuclei with $Z > 30$ from the combined standpoint of statistics and resolution.

TIGER INSTRUMENT

Instrument Overview--The TIGER instrument cross-section is shown in Fig. 1. It consists of four plastic scintillator dE/dx counters for charge measurements, two Cherenkov counters for velocity and charge measurements, and a scintillating fiber hodoscope to determine the trajectory of cosmic ray nuclei penetrating through the instrument.

Figure. 1--Tiger Instrument Cross-Section



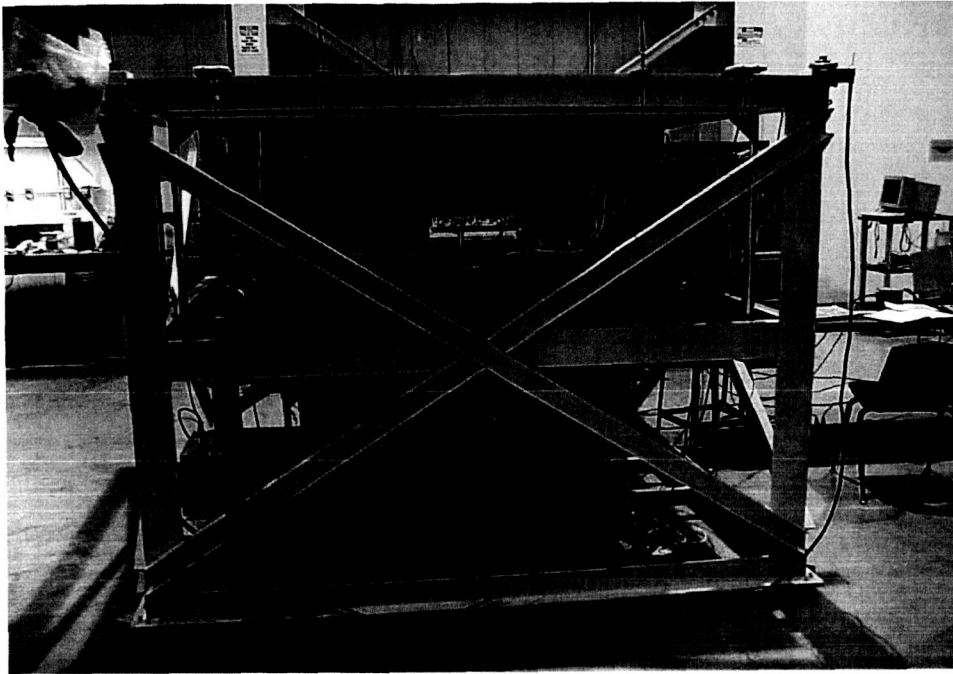


Figure 2--Photograph of TIGER mounted in gondola before EMI shielding and thermal insulation is added

In Figure 2 we show the TIGER instrument after integration into the gondola, but before the electromagnetic shielding (EMI) and the thermal insulation are added. The TIGER instrument occupies the upper half of the gondola and the NSBF data system occupies the lower half. Figure 3 shows TIGER in its launch configuration after the EMI shielding, thermal insulation, and solar panels are installed.

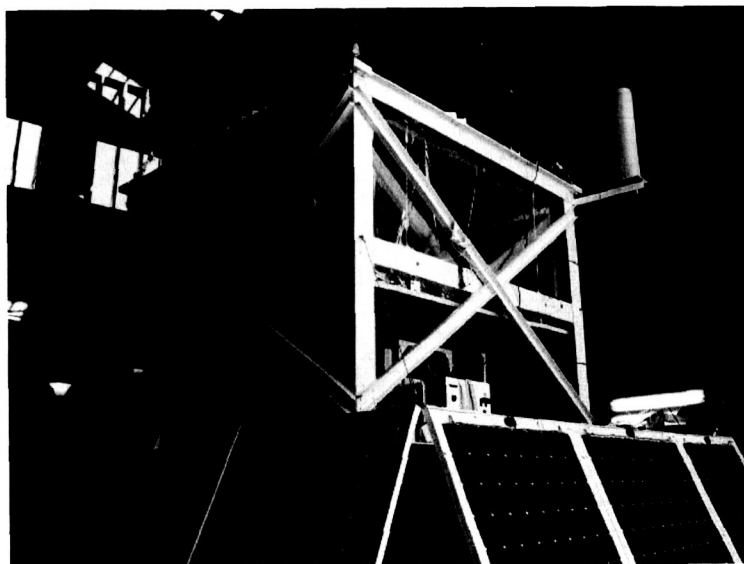


Figure 3--The TIGER instrument with EMI shield, thermal insulation, and solar panels installed.

The science weight of the instrument including the gondola is 1800 lbs. The power required is 100 watts. The required telemetry bit rate is 5.5 kbs.

RESULTS

In Figure 4a we show cross-plots of the summed signals from the top two plastic scintillator counters, S1 and S2, vs the acrylic Cherenkov signal. We see that the elemental charge contours are nicely separated in the Si-Fe region with the exception of events on the extreme right side of the contours, i.e. to the right of the left-most diagonal line. This is the region where relativistic rise in ionization results in an ambiguity in charge assignment based on these detector signals alone. For that reason, we included an aerogel Cherenkov counter in our instrument that has a characteristic turn-on energy of about 2.5 GeV/nucleon. In Figure 4b we plot the aerogel Cherenkov signal vs the acrylic signal. The lowest diagonal line on this figure corresponds to the line just discussed in Figure 4a; i.e. all of the particles above this line correspond to the particles to the right of the diagonal line in Figure 4a. Thus we see that the use of the aerogel counter has cleanly resolved the high energy particles that otherwise would have had an ambiguous charge determination.

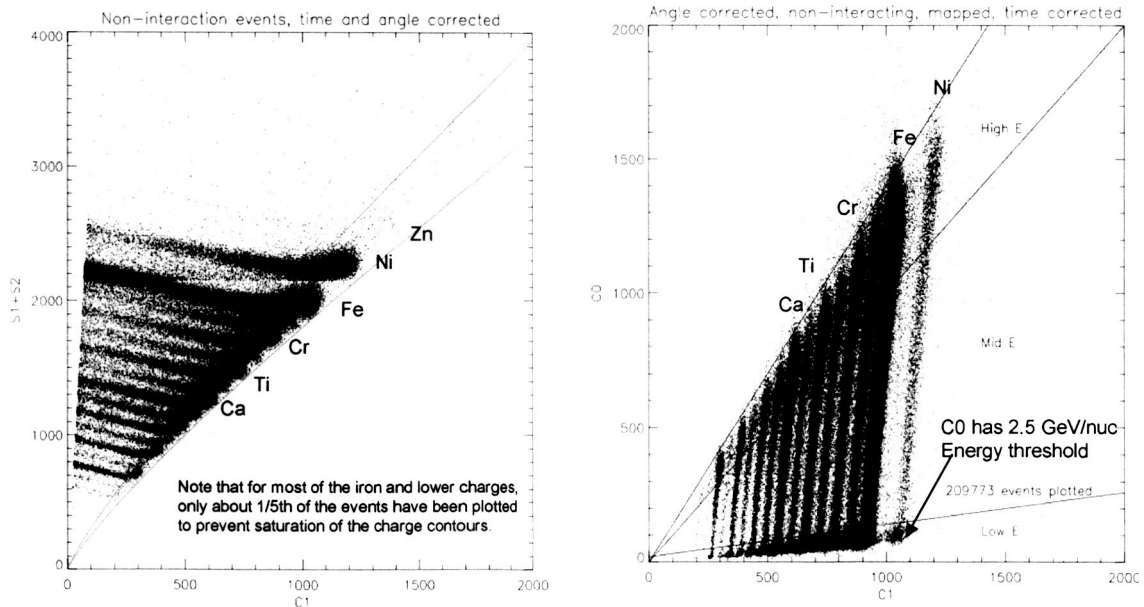


Figure 4—a) cross-plot of scintillator signals (S1+S2) vs the acrylic Cherenkov (C1) and
b) cross-plot of the aerogel Cherenkov (C0) vs the acrylic Cherenkov (C1)

The charge histogram that results from these data is shown in Figure 5.

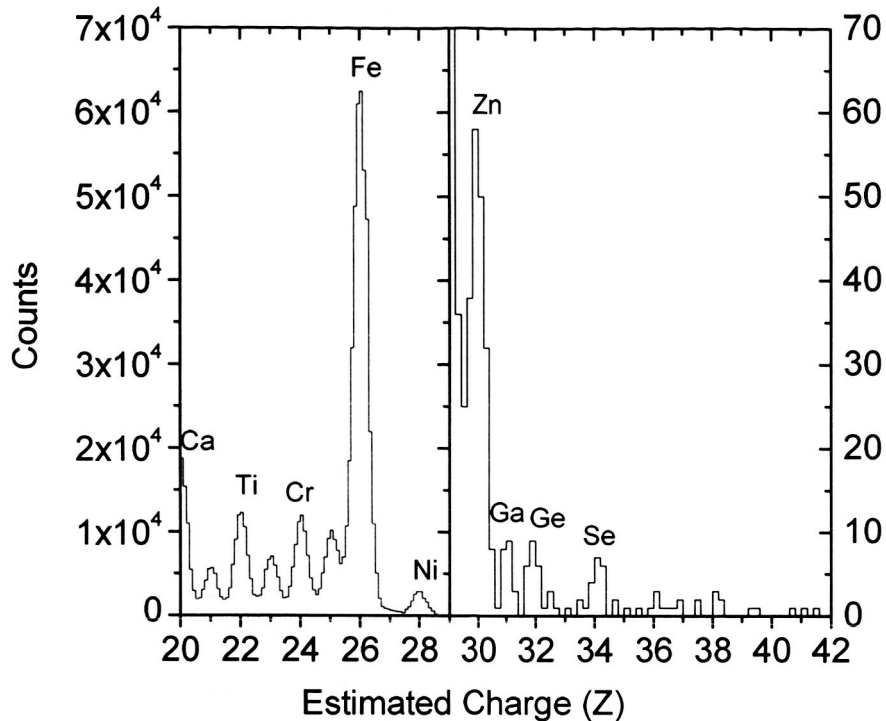


Figure 5—Charge histogram of cosmic ray data. Note the change in scale of a factor of 1000 for $Z > 29$.

We see that for the $Z=20-28$ region, our resolution in charge is quite good and clearly sufficient to obtain the kind of resolution required to resolve nuclei in the Ultra-heavy region ($Z \geq 30$). Above $Z=29$ we see clearly resolved peaks at $Z=30, 31, 32$, and 34 . Although these are low statistics measurements, we believe that the combined good charge resolution and statistics represents the best measurements of these elements to date including data taken by the HEAO C-2 and C-3 experiments.

We have derived elemental abundances relative to iron for the ultra heavy nuclei and have compared them to propagated source models as is shown in Figure 6. The curve labeled SS+FIP was obtained by propagating a source consisting of solar system abundances with a first-ionization-potential fractionation and the curve labeled SS+Vol was obtained similarly for a source of solar system abundances that is fractionated according to the element's volatility.

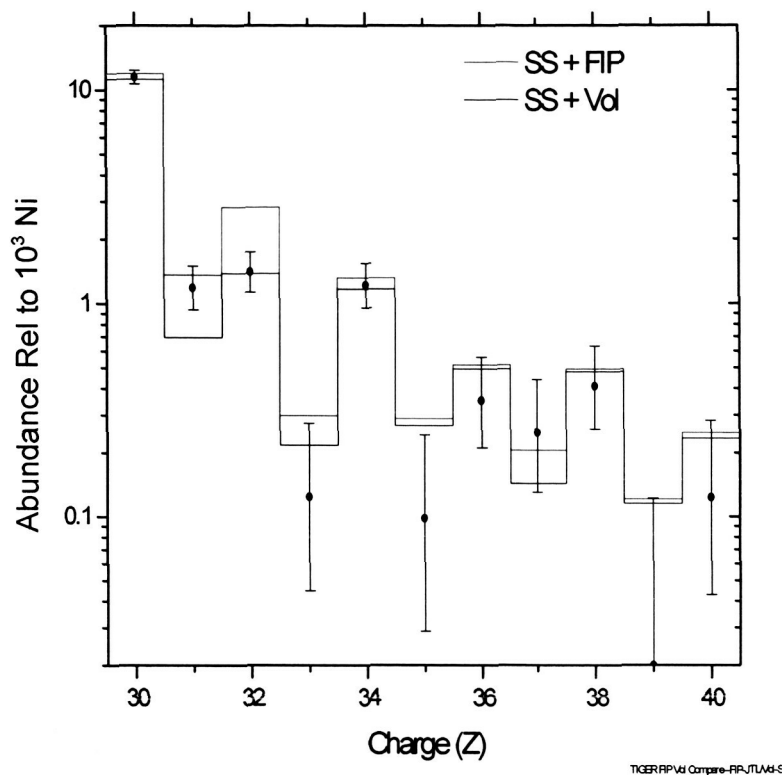


Figure 6—Comparison of TIGER data with propagated source abundance models.

The data agree best with a model that assumes that the source consists of solar system abundance material fractionated by volatility. In particular, Germanium ($Z=32$) agrees well with a volatility fractionation. However, Gallium ($Z=31$), appears to agree better with a FIP fractionation. It is clear that additional data are required for a firm conclusion and additional modeling with updated cross-sections would also be desirable.

We have flown TIGER a second time from Antarctica (2003-2004) and are currently working on analysis of that data.

Publications

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Link, J.T., et al. 2003, Measurements of the Ultra-Heavy Galactic Cosmic Ray Abundances between $Z=30$ and $Z=40$ with the TIGER Instrument, 28th ICRC, Tokyo, Japan 4, 1781

Geier, S. et al. 2003, Possible Detection of Large Solar Particle Event at Balloon Altitudes During the TIGER 2001-2002 Flight, 28th ICRC, Tokyo, Japan 4, 3261

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deNolfo, G.A. et al., 2005, Co/Ni Ratio Between $\sim 0.35 - 8.0$ GeV/nucleon from the TIGER-2001 Flight, 29th ICRC, Pune, India, Session OG1.1, usa-barbier-L-abs1-og11-oral

Theses

Link, J.T., Measurements of Ultra-Heavy Galactic Cosmic Rays with the TIGER Instrument, PhD dissertation 2003 Washington University

Papers Presented

Binns, W.R. et al. 2004, Elemental Abundances of Nuclei with $30 \leq Z \leq 40$ in Galactic Cosmic Rays, Paper presented at COSPAR 2004, Paris

Binns, W.R. et al. 2004, A Proposed Large-Area Instrument to Measure UH Elemental Abundances: Super-TIGER, Paper presented at COSPAR 2004, Paris

In addition, TIGER papers were presented at the APS-2002, 2003, and 2004 meetings.